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James R. Dickson
CTI and Associates

Andrew Lonergan
CTI and Associates

Rob Stenson
CTI and Associates

Chris Winkeljohn
CTI and Associates

Chapter 15

AN INTEGRATED SITE WIDE APPROACH TO CHLORINATED SOLVENT SOURCE REMEDIATION IN AN ACTIVE MANUFACTURING FACILITY

James R. Dickson[1§], Andrew Lonergan[2], Rob Stenson[3], and Chris Winkeljohn[4]
[1]*CTI and Associates, 1202 W. Washigton Ave, P.O. Box 276, Cleveland, WI, 53015-0276,* [2]*CTI and Associates, 12486 Emerson Drive, Brighton, MI 48116,* [3]*CTI and Associates, 1202 W. Washigton Ave, P.O. Box 276, Cleveland, WI, 53015-0276,* [4]*CTI and Associates, 12486 Emerson Drive, Brighton, MI, 48116*

ABSTRACT

The discovery of chlorinated volatile organic compounds (CVOCs) in the aquifer underlying a manufacturing facility prompted the initiation of an aggressive voluntary site wide soil and groundwater cleanup. Given a large number of potential source areas within the plant, delineation of CVOC impacts to the unsaturated zone was performed by the installation of an innovative soil vapor extraction system, rather than performing extensive soil sampling within the operating manufacturing facility. The system was designed with a pneumatically actuated valve manifold system to cycle the 120 extraction points which allowed for delineation of impacts, targeting hot spot source area removal, and overall contaminant reduction while remaining below regulatory discharge requirements, thereby eliminating the need for more costly air treatment. The innovative system design reduced equipment size by 80% while improving system recovery by operating in the most productive range of the removal curve. The groundwater remediation system, consisting of 6 extraction wells and 7 injection wells, is capable of extracting up to 600 gallons per minute (gpm) of groundwater. Up to 200 gpm of the extracted groundwater is treated by shallow tray air strippers with subsequent discharge via NPDES permitted outfall and re-injection of up to 400 gpm of substrate augmented groundwater into the upgradient portion of the plume. The net loss from the NPDES discharge provides capture and treatment of offsite groundwater downgradient of the site. The groundwater remediation system operates as a closed loop bioreactor allowing downgradient microbial seed to be recycled into the up gradient heart of the plume to increase the rate and effectiveness of CVOC removal via reductive dechlorination. Operations have so far have removed over 900 pounds of CVOCs from the unsaturated zone and over 1500 pounds CVOCs from the groundwater within the treatment zone. Groundwater treatment is ongoing.

Keywords: soil, groundwater, remediation, bioremediation, SVE.

§ Corresponding Author: James R. Dickson, 1202 West Washington Ave., P.O. Box 276, Cleveland, WI, USA, 53083, Phone: 920-560-1820, email: jdickson@cticompanies.com.

1. INTRODUCTION

The site is an anonymous active manufacturing facility located above a buried valley sole source aquifer in the Midwest consisting primarily of sand and gravel with a glacial till lower confining layer at about 80 feet below ground surface (BGS). The groundwater at the site is 20 feet BGS resulting in 60 feet of saturated thickness. The groundwater flow at the site is controlled by the surrounding rivers flood control structures and lakes. The flow is generally from the impoundment located north and west of the site and from the lakes located east and southeast of the site to the common regional discharge area near the confluence of the two rivers. The site layout is shown in Figure 1.

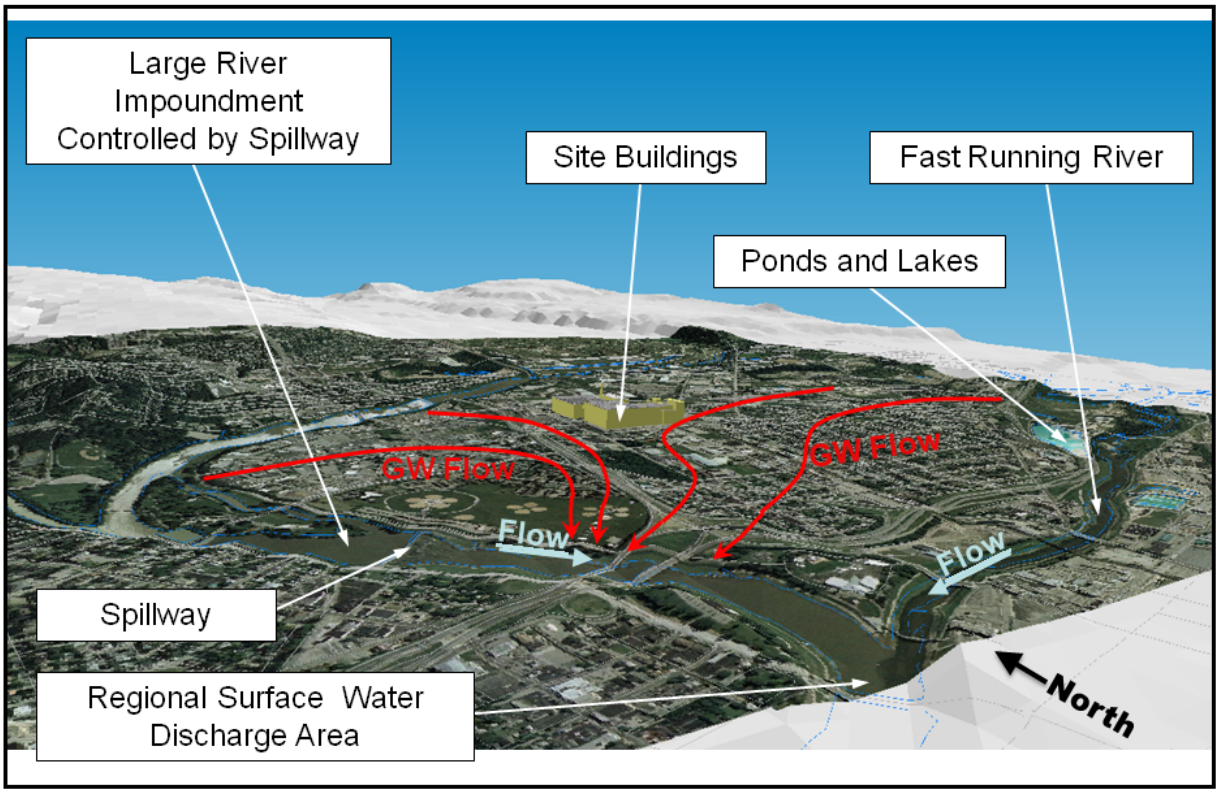

Figure 1. Site location and basin layout map looking from the southwest with ten times (10x) vertical exaggeration.

During original design, the groundwater flow direction was thought to have varied up to 90 degrees, either from the west or from the north. The typical flow was believed to be from the northwest to the southeast. This required a flexible design for the remediation system to allow for capture at the site boundary. The actual groundwater flow direction was later determined to be relatively constant and the historical interpretation was found to be an error caused by poor groundwater data collection techniques utilized for the extremely prolific aquifer.

The chemicals of concern in the basin consist of chlorinated degreasers and their associated breakdown products. The parent contaminants identified within the basin are tetrachloroethene (PCE), trichloroethene (TCE) and 1,1,1-trichlorothane (TCA). In addition to the site's plume,

there are multiple commingled plumes of chlorinated solvents in the site's immediate vicinity. Some of these off-site source plumes, primarily from the northeast where an existing pump and treat system is being operated, migrate or have migrated onto the site and mixed with the plume emanating from site itself as shown in Figure 2.

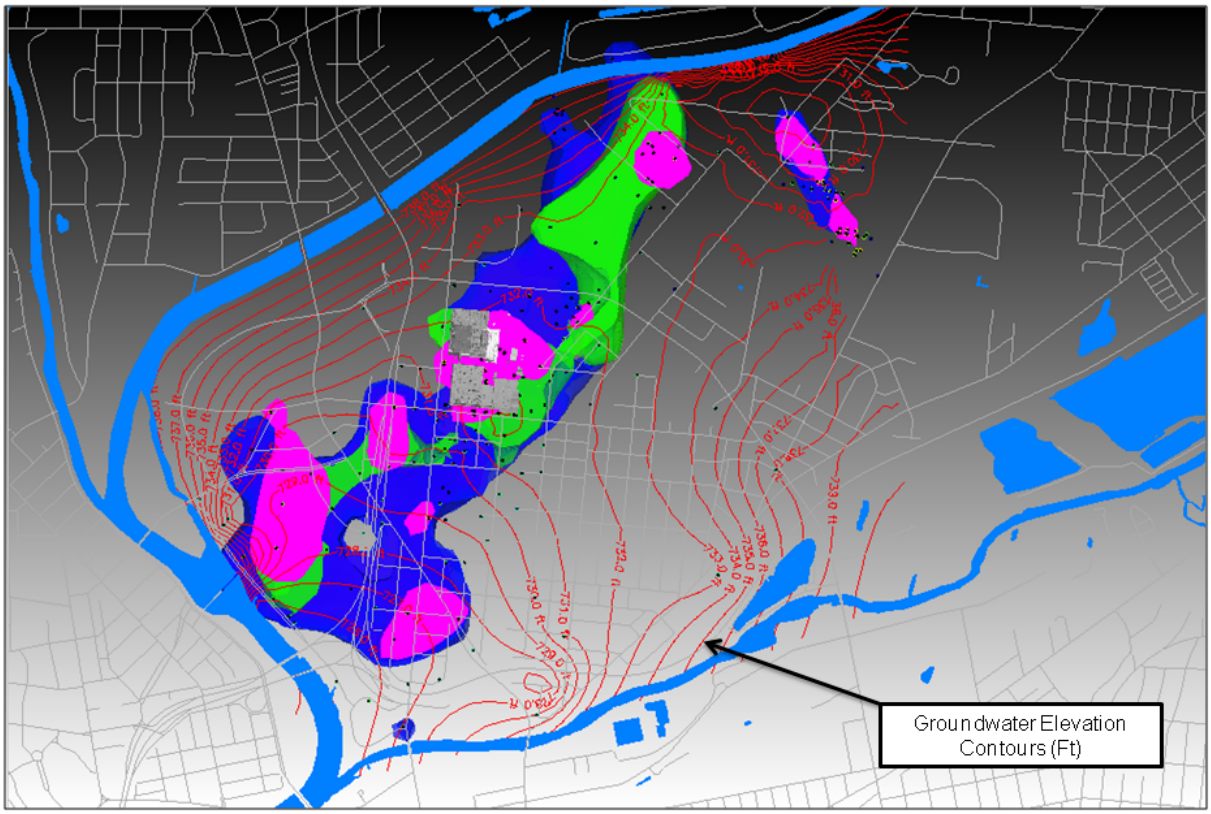

Figure 2. The location of the identified chlorinated parent compounds above 5 ug/L. These consist of PCE in magenta, TCE in blue, and TCA in green. The site is located near the center of the figure shown in gray.

The highest concentrations of parent contaminants identified on site before remediation in 2003 are as follows:

PCE – 8,000 ppb

TCE – 10,000 ppb

TCA – 1,000 ppb

1.1 Site Sources

The potential source areas for the manufacturing facility consist of vapor degreasers, sumps, sewers, and tanks located throughout the facility with the exception of the warehouse and receiving areas located in the northwest buildings. The plume characterization is presented in

another paper in these proceedings entitled "Characterization of Multiple Chlorinated Solvent Plumes due to the Impact of TCE Screening Level Reduction."

1.2 Site Goals

This project had two goals. The first goal was to aggressively reduce the site soil and groundwater contamination while providing containment at the site property boundary. The second goal was to develop and use an active remediation system that is flexible enough to address varying site conditions made evident by on-site and off-site plume characterization that was proceeding concurrently. In addition, the facility was active and very busy at the time of this work. The investigation work and remediation required completion with minimal impacts on the operations and production of the facility. This required close coordination with plant activities to minimize and prevent production delays.

2. MATERIALS AND METHODS

An integrated site-wide approach was applied for investigation and remediation of both soil and groundwater under a voluntary action. The soil remediation began first with groundwater system construction and groundwater characterization proceeding simultaneously to reduce the implementation schedule.

2.1 Soil Investigation and Remediation

Historical soil investigations had determined that there was limited soil contamination at the facility. This conclusion was not consistent with observed groundwater impacts. In order to meet the objectives of the voluntary site cleanup an integrated characterization and remediation approach was used. The use of soil vapor extraction (SVE) was selected as a means to provide both cleanup of the site soils and characterize the target treatment of the source areas in the unsaturated zone (Michaels, 1991). The location of manufacturing equipment, support beams, and their associated footers, limited access for SVE well installation to the plant isles. A pilot study was performed to determine the radius of influence (ROI) and performance criteria for the soils beneath the facility. The ROI was determined to be 80 ft with 100 –inches of water applied to the well head.

A network of SVE wells were installed during low production times and at locations in the plant to minimize interference. This network was installed at or near support beams to facilitate the routing of piping up the inside of the beam to the overhead manifolds. The bottom ten feet of the riser pipes was made from steel to minimize damage from fork truck traffic and other facility equipment. The remaining runs were made of PVC to reduce cost and weight of overhead piping. Each well has a shut off valve and a quarter-inch threaded plug to allow for air flow/vacuum readings and air sample collection.

To maximize the system recovery while minimizing the size, the wells were connected in banks of up to 12 wells each with pneumatically operated isolation valves and plumbed via common manifold piping to one of two systems. The northern system was connected to Banks 1

through 6 located in the northern building and in the paved truckway between buildings. The southern system was connected to Banks A though H which are located in the southern buildings.

The SVE systems were prefabricated and consisted of three 25 HP regenerative blowers, a moisture knockout tank, a knockout tank pump, a storage tank, and associated manual controls all installed in a prefabricated 10 by 20 foot building. Two blowers are operated to meet the design parameters of 1000 SCFM at 100-inches of water at the most remote manifold. The third blower is an installed spare for rotation and maintenance.

The operation hose from each bank's pneumatic butterfly valve was run along the combined manifold piping and finished with hose quick connects at the SVE system locations. Two prefabricated 8 by 20 feet control buildings were used to house the dry air compressor system, analog timer panel with 10 timers, and 10 solenoid valves attached to the compressor manifold piping. Air hoses were used to allow for flexible connections to operate either a single or combination of bank pneumatic valves. The SVE system Layout is shown in Figure 3.

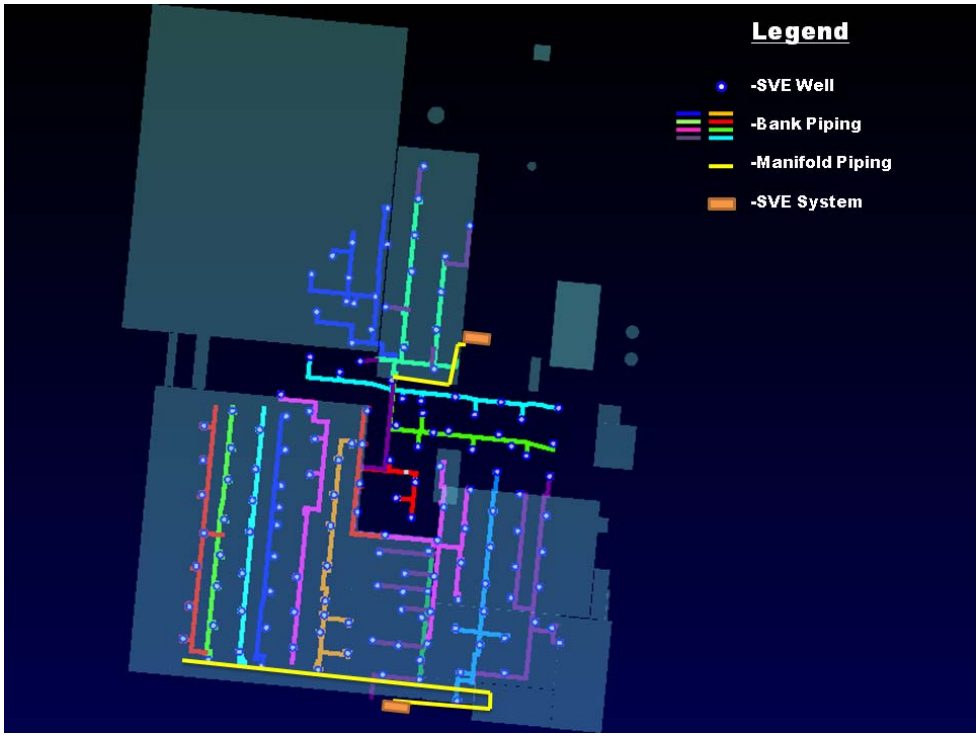

Figure 3. The Site SVE System Layout showing well, piping and system locations.

For the initial characterization operations, the systems were configured to use an additional moisture separator tank and activated carbon vessels as a precaution to be sure daily emissions were below regulatory requirements. These were designed to be easily removed to allow the system to operate as designed (i.e., without carbon) once initial levels extracted from the well had been determined.

2.2 Groundwater Investigation and Remediation

To meet the objectives of the voluntary site cleanup, the on-site groundwater remedy of reductive dechlorination via in-situ closed loop bioreactor was selected (ITRC, 2002). The system consists of up to 6 extraction wells located along the south and east sides of the facility based on initial groundwater flow from the northwest with a 45 degree fluctuation based on site characterization at the time. Each well is capable of pumping up to 100+ gpm with all wells running to the selected manifold. Each well can be directed to the treatment or injection manifold, which are identical and run parallel to each other through the overhead of the manufacturing facility. Both manifolds leave the manufacturing facility and run underground to an external treatment building located in an unused portion of the facility. In the treatment building, one manifold is connected to three shallow tray air strippers to allow for treatment prior to discharge via an NPDES permitted outfall. The other manifold runs through a flow meter, with an injection line for substrate addition, and can then be directed to any combination of up to 7 injection wells located on-site. After the substrate is added, the flow is re-injected directly and without treatment.

The on-site and off-site groundwater plume was characterized in the basin by the installation of 50 membrane interface probe (MIP) direct push borings to the confining layer with discrete groundwater samples from three depths per boring. Thirty temporary water table wells were installed throughout the basin to evaluate regional groundwater flow and 6 on-site well nests were installed to fill data gaps and provide monitoring in the treatment zone. This work was on-going while the groundwater treatment system was being constructed

The system was designed based on site characterization data available at the award of the project and construction was ongoing as questions regarding the groundwater flow direction were resolved. Upon competition of the construction of the system, the flow direction was confirmed and varied little during precipitation and surface water flow events. The new groundwater flow was found to enter the site radially from the northwest, north, northeast and east and then flow off site to the south southwest toward a common regional groundwater water discharge point located downgradient of the river spillway. This groundwater flow pattern is shown in Figure 4. As a result of better site characterization, two of the extractions wells were found to be upgradient of the site and two injection wells were found to be outside the capture lines of the extraction system. The two extraction wells found to be upgradient were converted to injection wells for the system. The two injection wells that were outside the system's capture zone were used for water level monitoring only. The modular system design allowed for system modification without substantial rework; only minor alterations were needed saving time and money.

The original design parameters for the system are extraction of up to 600 GPM from the groundwater, with (a) a 400 GPM stream continuously augmented with substrate (but otherwise untreated) and re-injected upgradient within the system capture zone and (b) 200 GPM stream treated in shallow tray air strippers and discharged via an NPDES permitted outfall providing a net loss to ensure site groundwater capture. The concept was that extracted groundwater would have bacteriological seed similar to the activated sludge of an activated sludge wastewater treatment plant. The augmented groundwater, with a carbon source substrate and then re-injected within the capture zone, would establish a treatment zone beneath the plant. This re-injection, in

conjunction with the treatment and discharge of a portion of the extracted groundwater creates an in-situ closed loop bioreactor for the groundwater remediation.

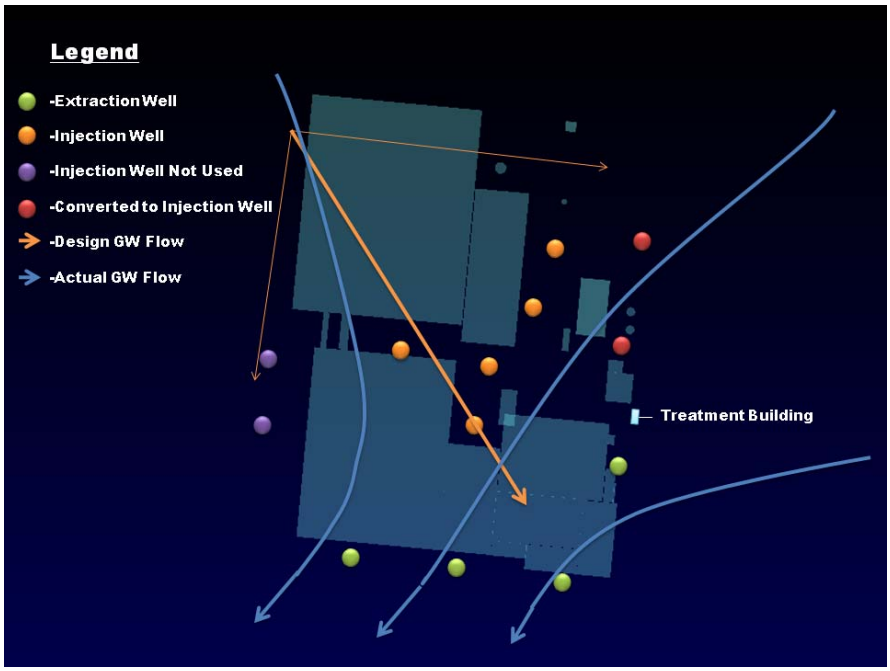

Figure 4. The Site groundwater treatment system location map showing design and actual groundwater flow directions.

Discharge from each extraction well was run through the air strippers one at a time to determine contaminant levels in that well prior to the system start-up. It was determined that the highest concentration wells would be sent to the air strippers to maximize mass removal of the system. Extraction well operational testing was conducted to optimize capture zone efficiency, contaminant removal, and recirculation effectiveness. It was found that capture could be maintained with two extraction wells running, one for treatment with subsequent discharge via the NPDES permitted outfall at approximately 120 GPM, and one to the augmentation and re-injection system at about 80 GPM.

The augmentation substrate selected for the project was sodium lactate and utilized on-site bulk storage in double walled tanks to allow for delivery by tanker truck reducing the cost of the substrate. The system pumps directly from the primary tank via a metering pump into the injection port located upstream of several pipe elbows to ensure thorough mixing. The second tank has a transfer system installed to allow for material transfer from the second tank to the primary tank via a submersible pump.

3. RESULTS AND DISCUSSION

The combined remediation system has removed over 2400 pounds of CVOC's from the site since operations began in 2003-2004 while providing containment at the site property boundary. The site plume distribution and groundwater flow regime have been fully characterized leading to a better understanding of contaminant distribution and other sources in the surrounding basin.

3.1 Soil Remediation Results

The soil vapor extraction system began initial site characterization testing in June of 2003 as a part of the integrated characterization and remediation approach. During initial characterization phase of the project systems, the extracted air was drawn through an external moisture knock-out tank followed by two 1000 lb carbon vessels in series to ensure that the daily discharge does not exceed the 10 pound per day maximum for the site. Each bank was operated for several hours with multiple gas samples collected from each bank well head, carbon influent, between carbon and after carbon. Gas samples were collected and analyzed by an on-site gas chromatograph (GC).

The on-site GC was used to streamline the investigation by giving preliminary results for each sample within 30 minutes of collection. The use of the on-site GC also dramatically reduced the time and cost associated with sample collection and analysis. The samples for the on-site GC were collected by syringe, transported to the on-site GC, and injected directly into the GC. Other methods of sample collection would have required the use of summa canisters or the filling of sample bags with a pump. Both of these methods would have required significantly more site labor, equipment/sample shipping /handling costs and significant increase in the project duration.

The data for each bank was compiled to verify the emission limits could be met without carbon and the whole process was repeated with the manifolds hooked directly to the system and discharged out the system stack. The overall construction and characterization testing program took a total of 60 working days complete. To allow for access in the truck way, work was completed on the weekends without truck traffic.

The initial phase of characterization testing began at lower than design vacuums and flow due to the addition of carbon in the treatment train. The characterization testing operated each bank with all valves open and measured extraction flow/vacuum at the well head. Contaminant concentration at the well head was determined by the on-site GC. As a contingency during the testing, if a sample concentration indicated the potential emissions were too high, the duration of the test could be shortened to prevent exceeding the air discharge requirements. Upon completion of the initial characterization, the results were plotted to provide a vapor distribution by concentration. The initial characterization test of each well head resulted in the total CVOC distribution as shown in Figure 5.

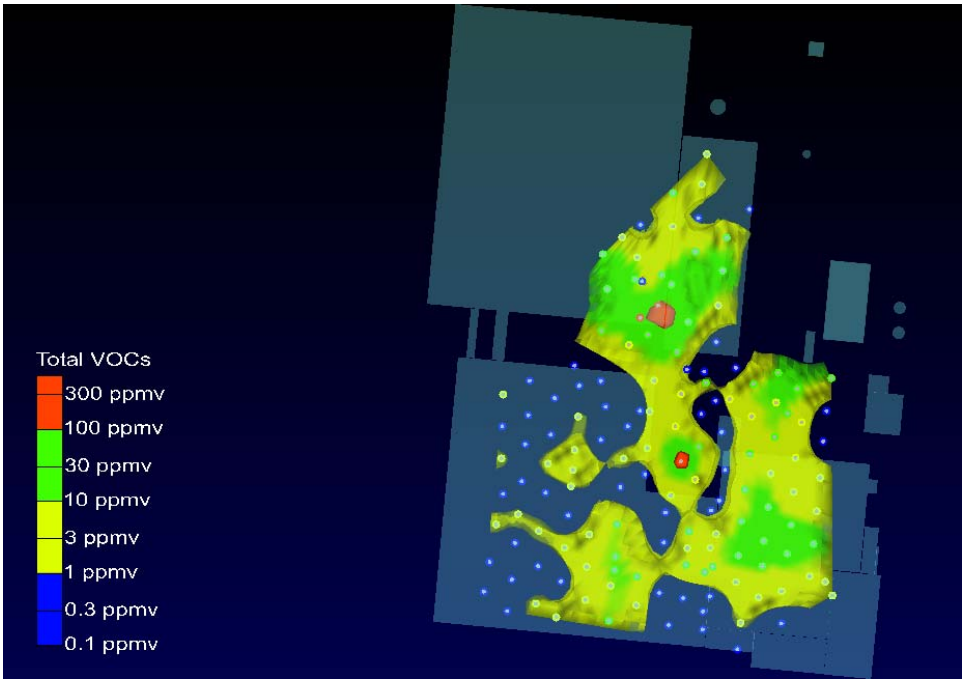

Figure 5. Total CVOC vapor distribution during initial characterization testing with activated carbon.

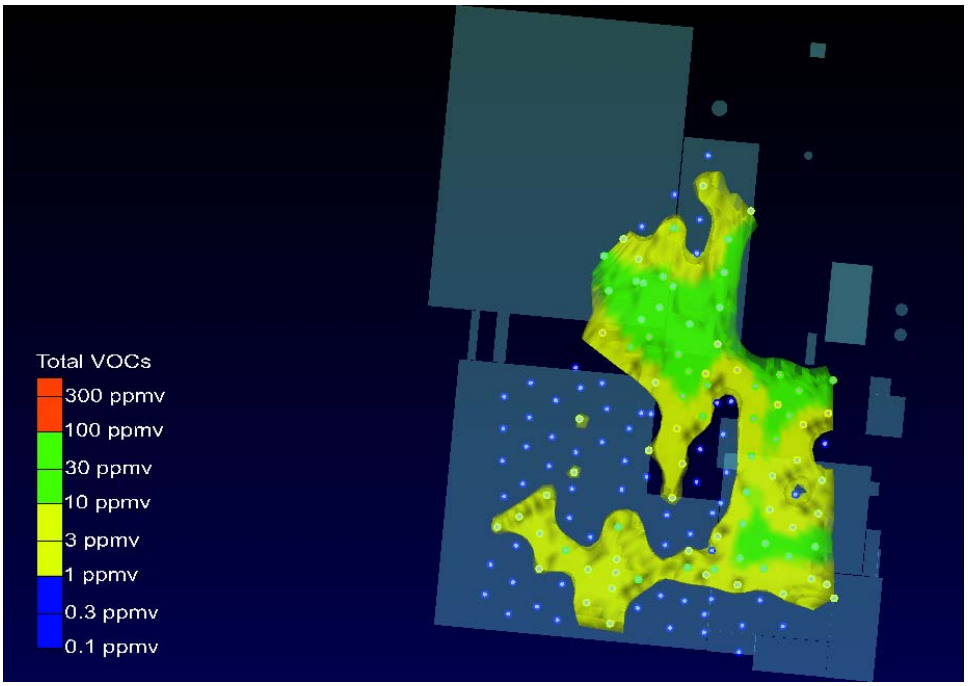

Figure 6. Total CVOC vapor distribution at the end of the site characterization phases.

Once worst case well head concentrations were known, the second phase of characterization testing was performed without carbon to demonstrate removal concentration and flow rates at system design conditions. The results were again plotted to determine vapor distribution shown in Figure 6.

Upon completion of the characterization phase testing, the system was configured to maximize mass removal from the areas with the highest vapor concentrations while staying below the maximum allowed emissions. This was performed by joining multiple banks together and closing all but the selected vapor extraction wells of the combined banks to target areas with the highest vapor concentrations. The initial characterization data was used to combine banks and wells for the targeted removal in these areas.

The system was then operated in that configuration for the next quarter (1st quarter 2004). During that time samples were collected weekly from each of the combined banks at the inlet of each system and sent to an off-site laboratory for analysis. The results in the parts per billion by volume (ppbv) range were then used to monitor mass removed and document that the systems were in compliance with emission limitations.

The on-site GC was mobilized back to the site for the first quarterly monitoring event at the end of the first quarter. The SVE systems were shutdown and reconfigured with all wells open and operations of one bank at a time. Each bank was put on-line and each well head was sampled in the same manner used in the initial characterization testing.

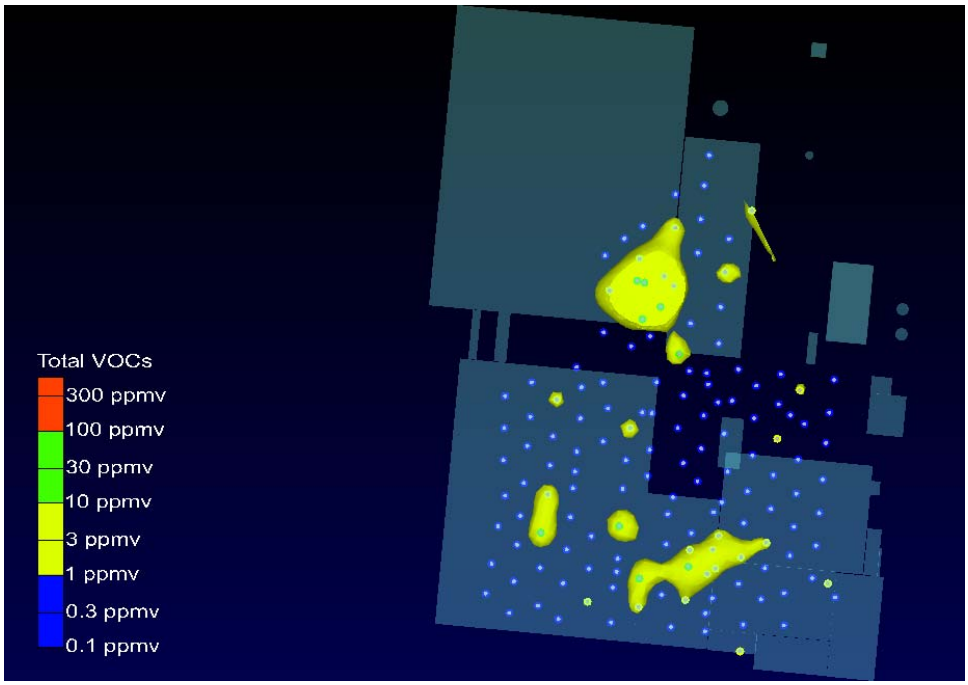

Figure 7. Total CVOC vapor distribution after six months of targeted hot spot removal.

The 1st quarter 2004 results indicated that only 33 out of 120 extraction points had results above 1 parts per million by volume (ppmv), the detection limit of the on-site GC used, when

compared to the 95 well points during the initial characterization above 1 ppmv and 84 well points at the end of the characterization period. This indicated that the on-site GC was no longer cost effective for future monitoring and quarterly sampling events were then discontinued. The well head concentration results for the end of targeted removal are shown in Figure 7.

After the targeted removal was completed, the systems were run with all wells and all banks on-line for the next year resulting in the removal of an additional 393.7 pounds of VOCs for a total of 880 pounds of VOCs removed by the systems. The results are summarized in the following table.

Sampling Event	SVE Wells <1 PPMV	SVE Wells 1-10 PPMV	SVE Wells 10-100 PPMV	SVE Wells >100 PPM	Pounds of CVOCs Removed
Initial Sampling (with Carbon)	25	53	39	3	23.2
End of Startup Period	36	45	39	0	65.9
End of initial of Targeted Removal	87	24	9	0	397.2
End of Normal Operations	-	-	-	-	393.7
Total					880
Indicates that individual well head concentrations were no longer analyzed.					

For the SVE system overall, 10% of total mass was removed during site characterization, 45% was removed during the subsequent 6 months of targeted operations and the remaining 45% of mass recovered was removed during the 1.5 years of normal system operations. The SVE systems (north and south) were shut down in early 2006.

3.2 Groundwater Remediation Results

The initial overall plume characterization work was completed in November of 2003. This information was used as the baseline for comparison of the system progress. The groundwater system began operations on June of 2004 and has operated continuously until the most recent sampling event in February of 2008. An average of 8.6 million gallons per month is extracted at the facility boundary of which 3.5 million gallons is augmented with 318 mg/L of sodium lactate, and then re-injected upgradient of and into the center of the site. The treatment results are shown in the figures below.

PCE concentrations in the groundwater within the property line decreased 51% since system operations began in 2004. During system operations, 75 ppb of PCE on average were injected untreated along with the substrate to the active injection wells. The 2003 and 2008 results for PCE are shown in Figures 8 and 9.

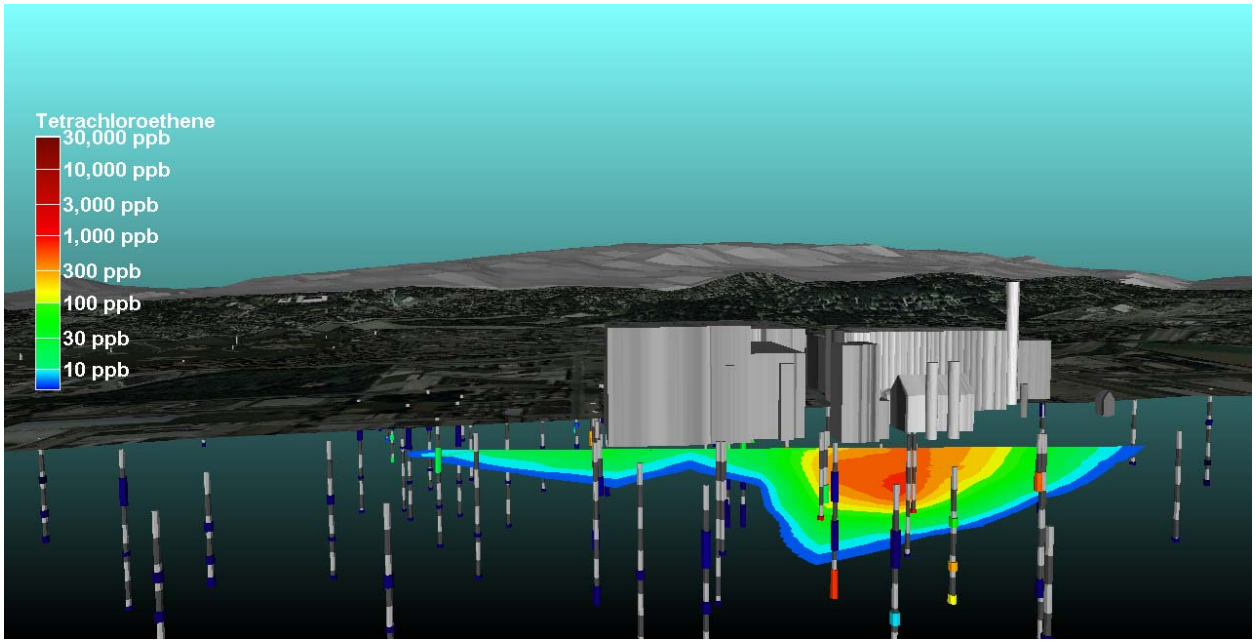

Figure 8. Profile view of PCE distribution before groundwater treatment began in 2003 looking east.

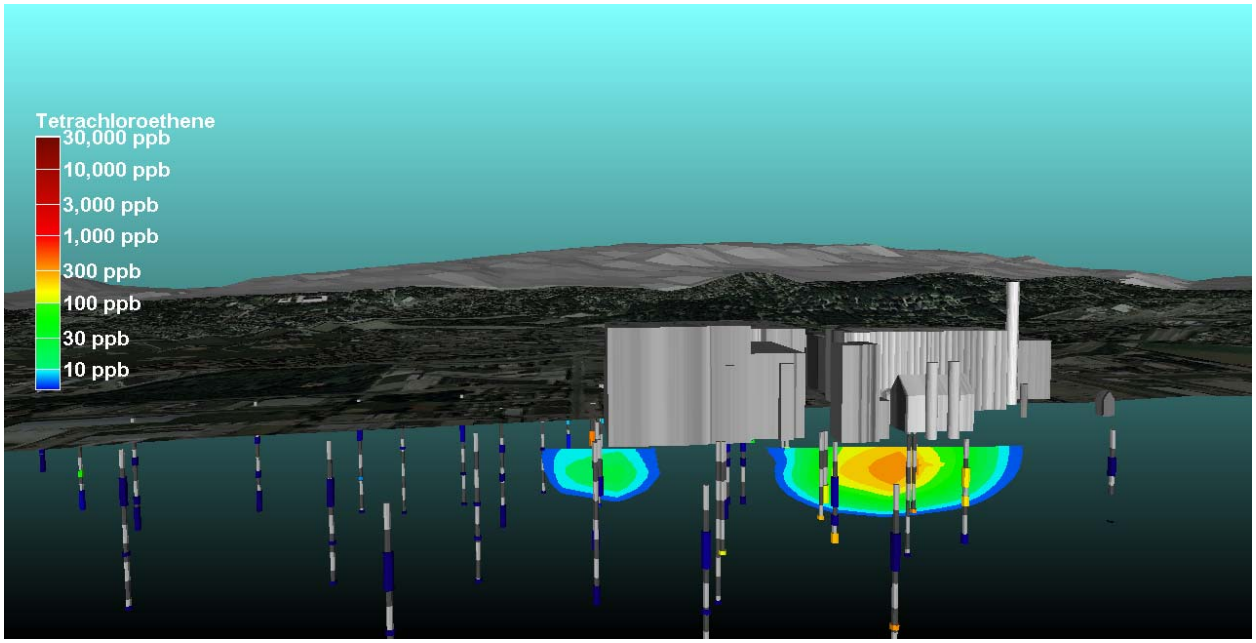

Figure 9. Profile view of PCE distribution as of February 2008 after 4 years of operations looking east.

The concentrations of TCE in groundwater decreased 39% within the property boundary since system operations began in 2004. During the system operations, 750 ppb of TCE on average were injected untreated along with the substrate to the active injection wells. It should also be noted that TCE impacted groundwater continues to migrate on-site from upgradient off-site sources. The 2003 and 2008 results for TCE are shown in Figures 10 and 11.

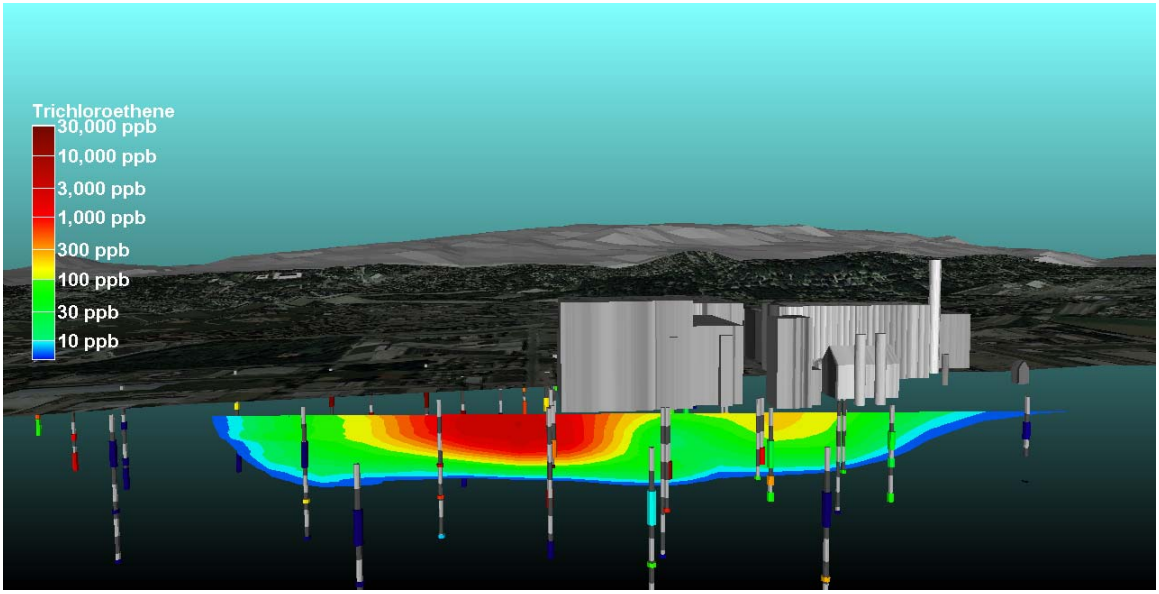

Figure 10. Profile view of TCE distribution before groundwater treatment began in 2003 looking east.

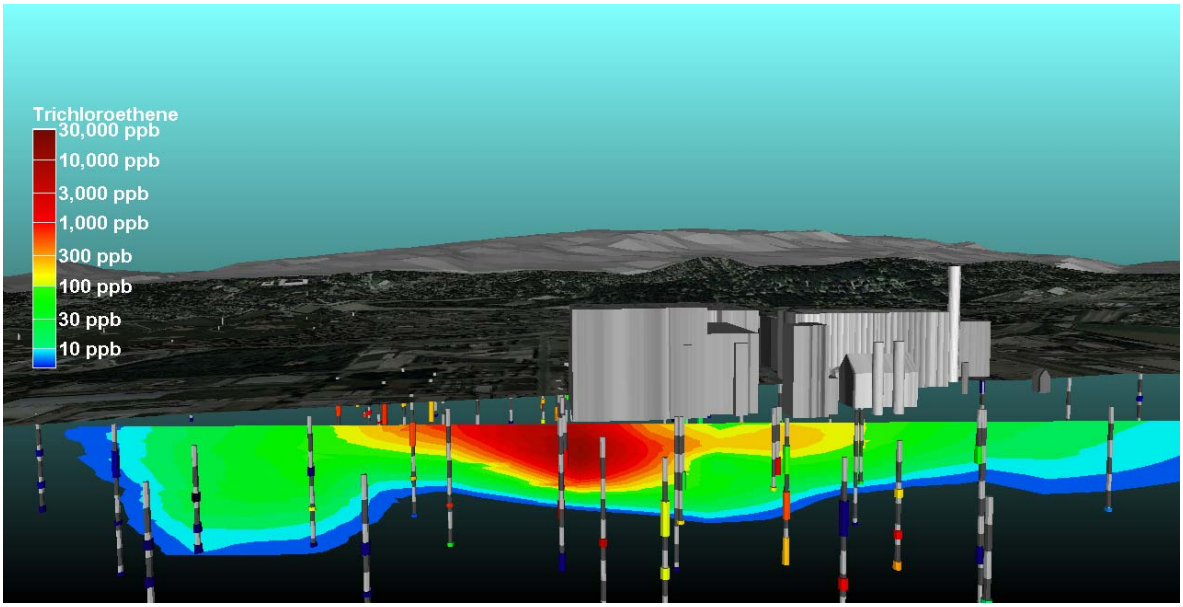

Figure 11. Profile view of TCE distribution as of February 2008 after 4 years of operations looking east.

Within the property boundary, the concentration of CDCE in groundwater has decreased 52% since the system began operations in 2004. An average of 150 ppb of CDCE was injected untreated along with the substrate to the active injection wells. The concentrations actually increased in 2006 with subsequent decreases as monitoring continued. This is consistent with the typical breakdown of PCE and TCE into its daughter products via reductive dechlorination (Alvarez & Illman, 2005). The 2003 and 2008 results for CDCE are shown in Figures 12 and 13.

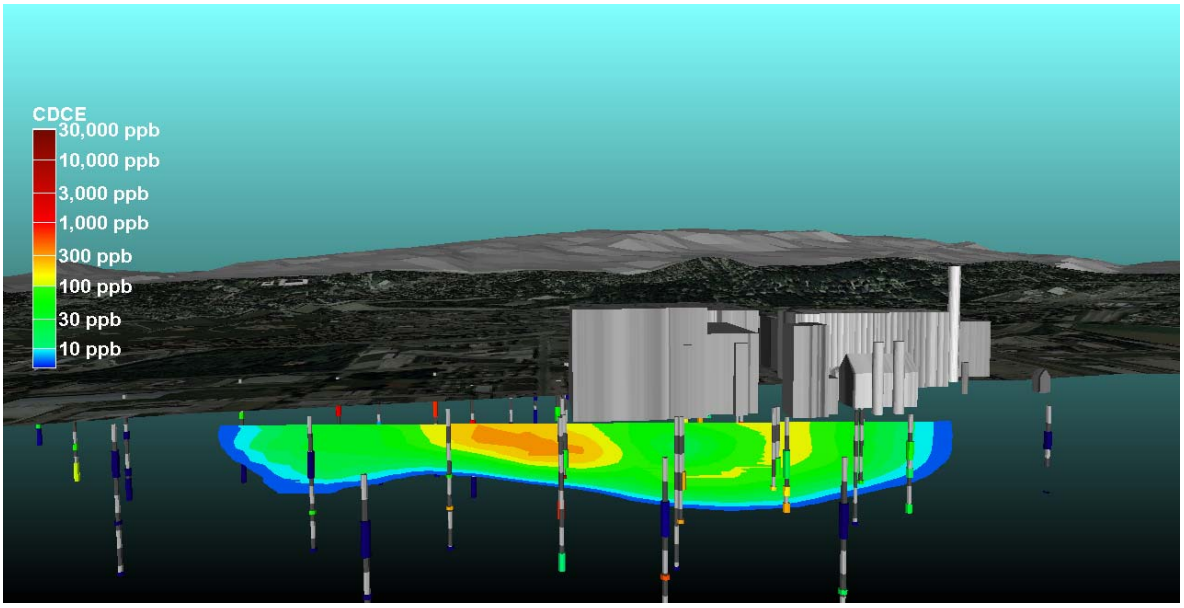

Figure 12. Profile view of CDCE distribution before groundwater treatment began in 2003 looking east.

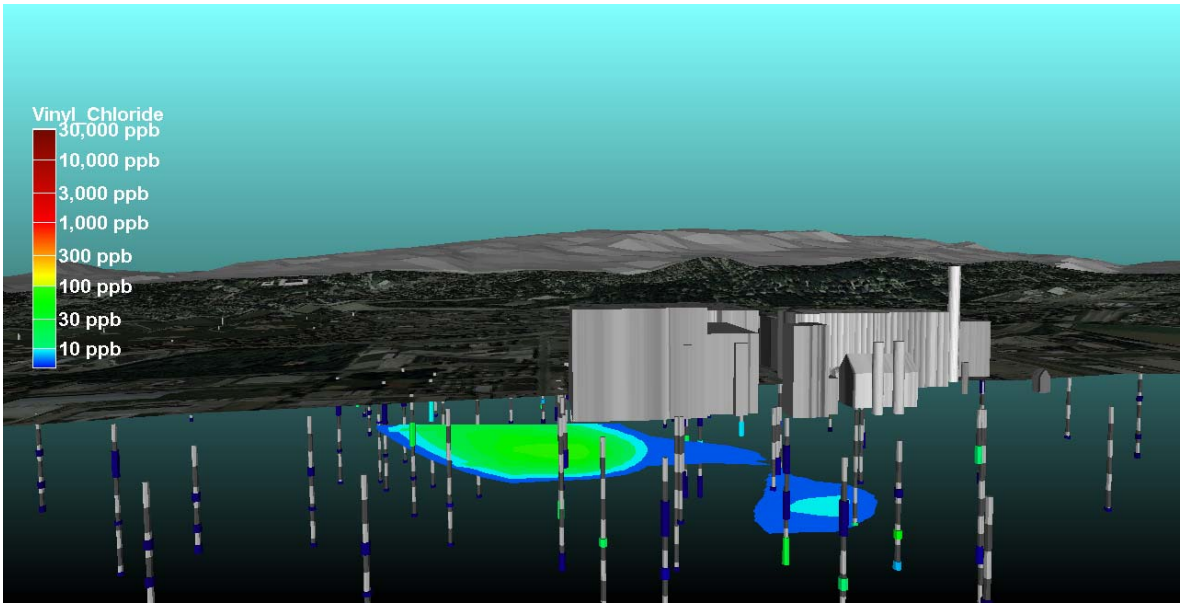

Figure 13. Profile view of CDCE distribution as of February 2008 after 4 years of operations looking east.

Vinyl chloride concentrations in groundwater within the property boundary have increased by 112% since system operations began in 2004. During system operations, 7 ppb of vinyl chloride on average were injected untreated along with the substrate to the active injection wells. The stoichiometric transformation of PCE, TCE and CDCE to vinyl chloride would have been expected to result in an increase of 945% or greater if reductive dechlorination had stalled at vinyl chloride. The 2003 and 2008 results for vinyl chloride are shown in Figures 14 and 15.

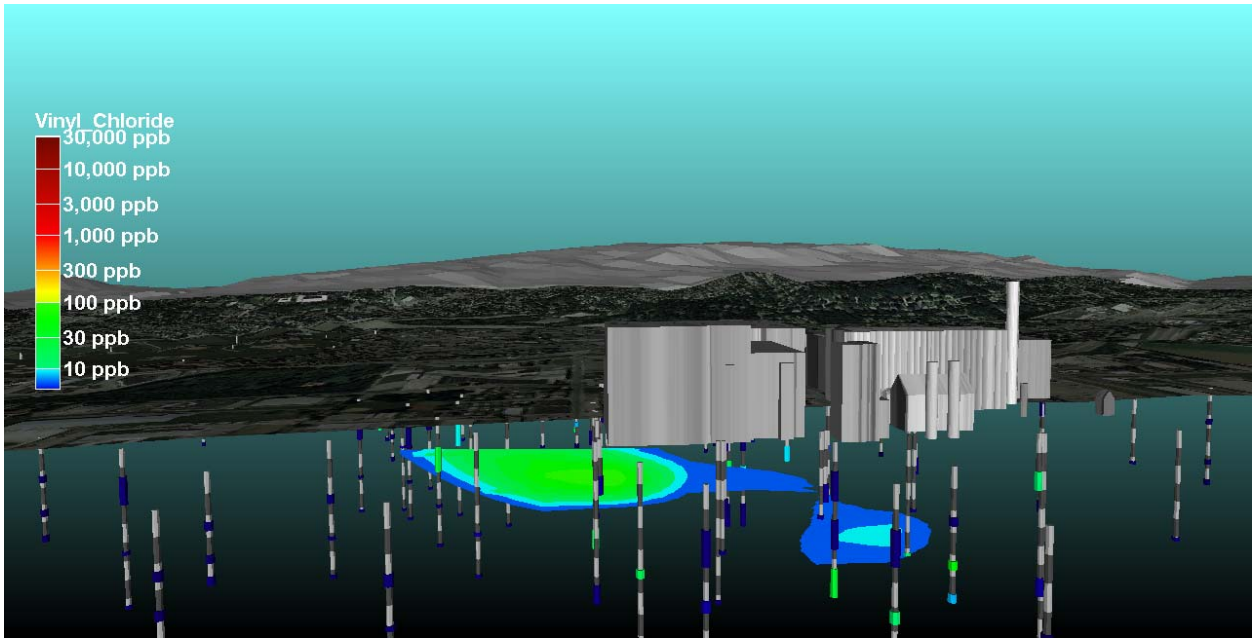

Figure 14. Profile view of vinyl chloride distribution before groundwater treatment began in 2003 looking east.

4. CONCLUSION

The integrated site wide approach provided a means to streamline the site characterization while proceeding directly into remediation under the voluntary action program. The concept of designing flexibility into the remediation system to allow for ease of enhancements to optimize the system based on performance monitoring data allowed for an efficient implementation of system characterization into remedial action.

The integrated approach to soil characterization and remediation resulted in site soil characterization; SVE system construction, system optimization, and significant contaminant mass removal being completed in the time it would take to perform a traditional soil investigation within an operating facility. In addition, characterization and construction of the system caused minimal interference to plant operations.

The groundwater remediation approach of in-situ closed loop bioreactor with flexible system design has provided the following results:

Full scale operation of the integrated system began faster than the conventional investigate/design/build/operate model.

The containment of further off-site migration of site contaminants was achieved very quickly.

The integrated flexibility of the design allowed for rapid and inexpensive on-going system performance optimization as additional on-site and off-site characterization data became available.

As of February 2008, this combined approach for the site has provided the removal of 880 pounds of CVOCs from site soils and an estimated 2000 pounds of CVOCs from site groundwater. The system prevents further off-site migration of site contaminants while continuing to reduce contaminant mass on-site. The migration on-site from off-site sources continues to be an ongoing issue and slows site progress.

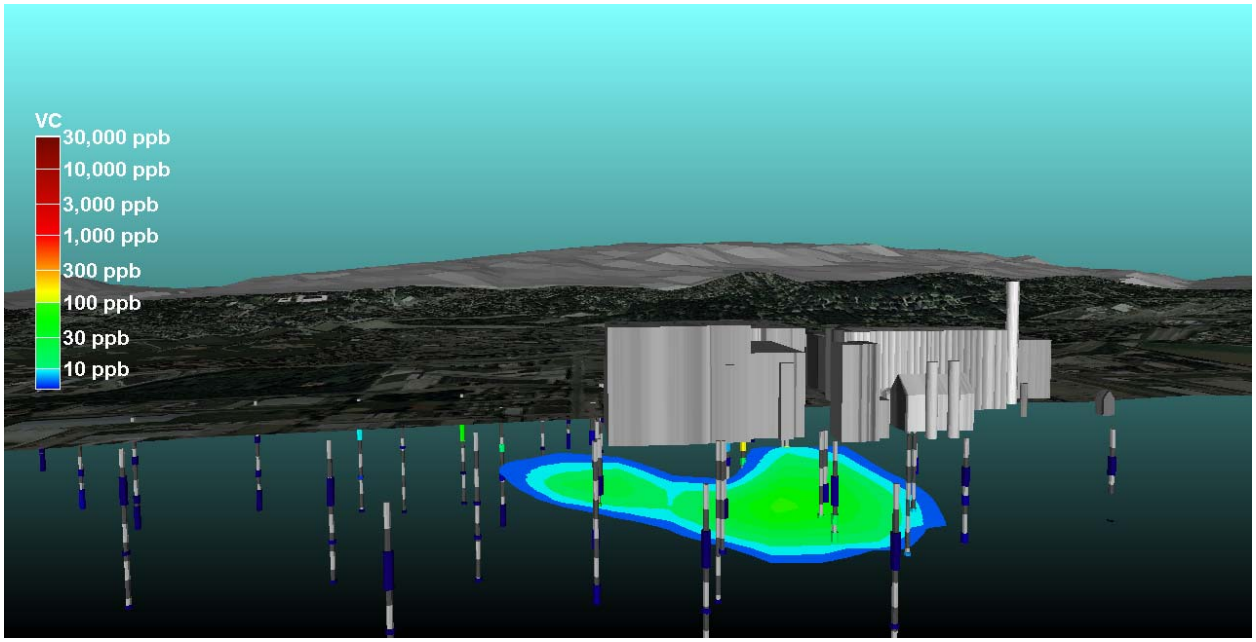

Figure 15. Profile view of vinyl chloride distribution as of February 2008 after 4 years of operations looking east.

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